The Temporal and Probabilistic Relationship between Lightning Jump Occurrence and Radar-Derived Thunderstorm Intensification

- Christopher J. Schultz[1], Lawrence D. Carey[2], Themis Chronis[3], Sarah M. Stough[2], and D. J. Cecil[1]

- 1- NASA MSFC, Huntsville, AL
- 2- Department of Atmospheric Science, University of Alabama Huntsville
- 3- Earth System Science Center, University of Alabama Huntsville

The Lightning Jump

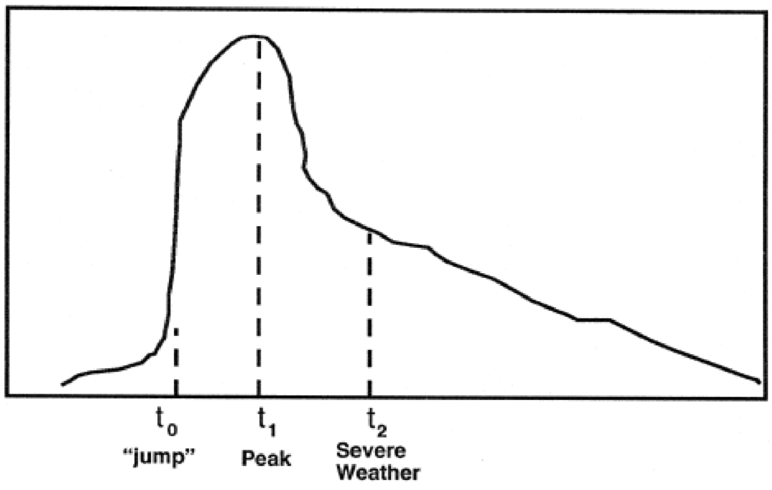
Earth Science Office

- Rapid increases in total lightning (i.e., “lightning jumps”) are statistically related to updraft intensification (speed and volume) and well-correlated to severe weather occurrence.
  - Williams et al. 1999, Schultz et al. 2009, Gatlin and Goodman 2010, Schultz et al. 2016

1) Helps forecasters identify rapid intensification of storms.

2) Increases forecaster confidence in a warning decision.

Figure credit : Williams et al. 1999, Atmos. Res.



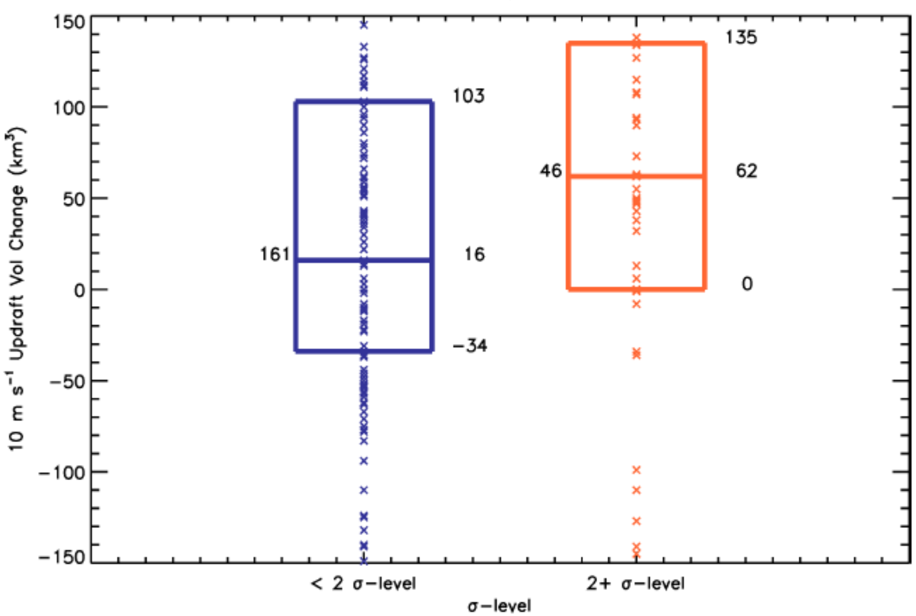
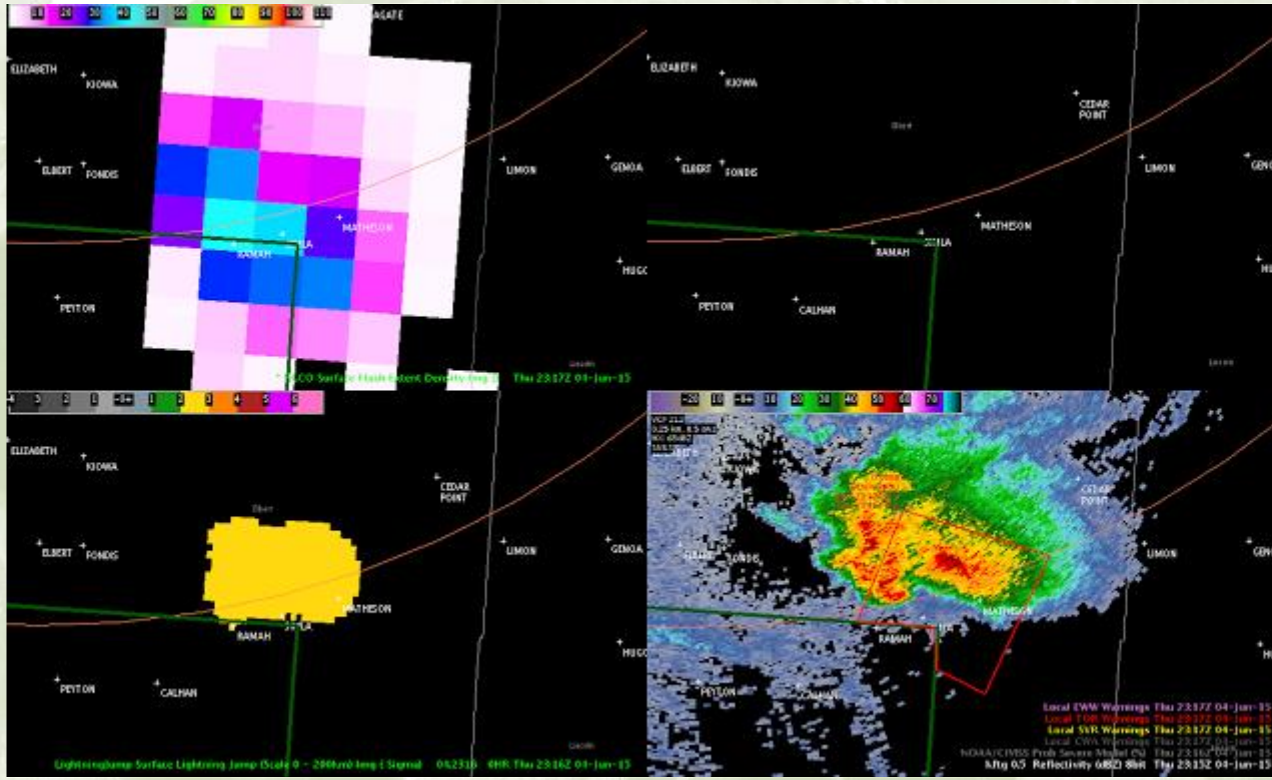


Figure credit : Schultz et al. 2016, in revision

Operational Status

Earth Science Office

MRMS suite will have the lightning jump in build 12
- First uses ENTLN
- Transitions to GLM

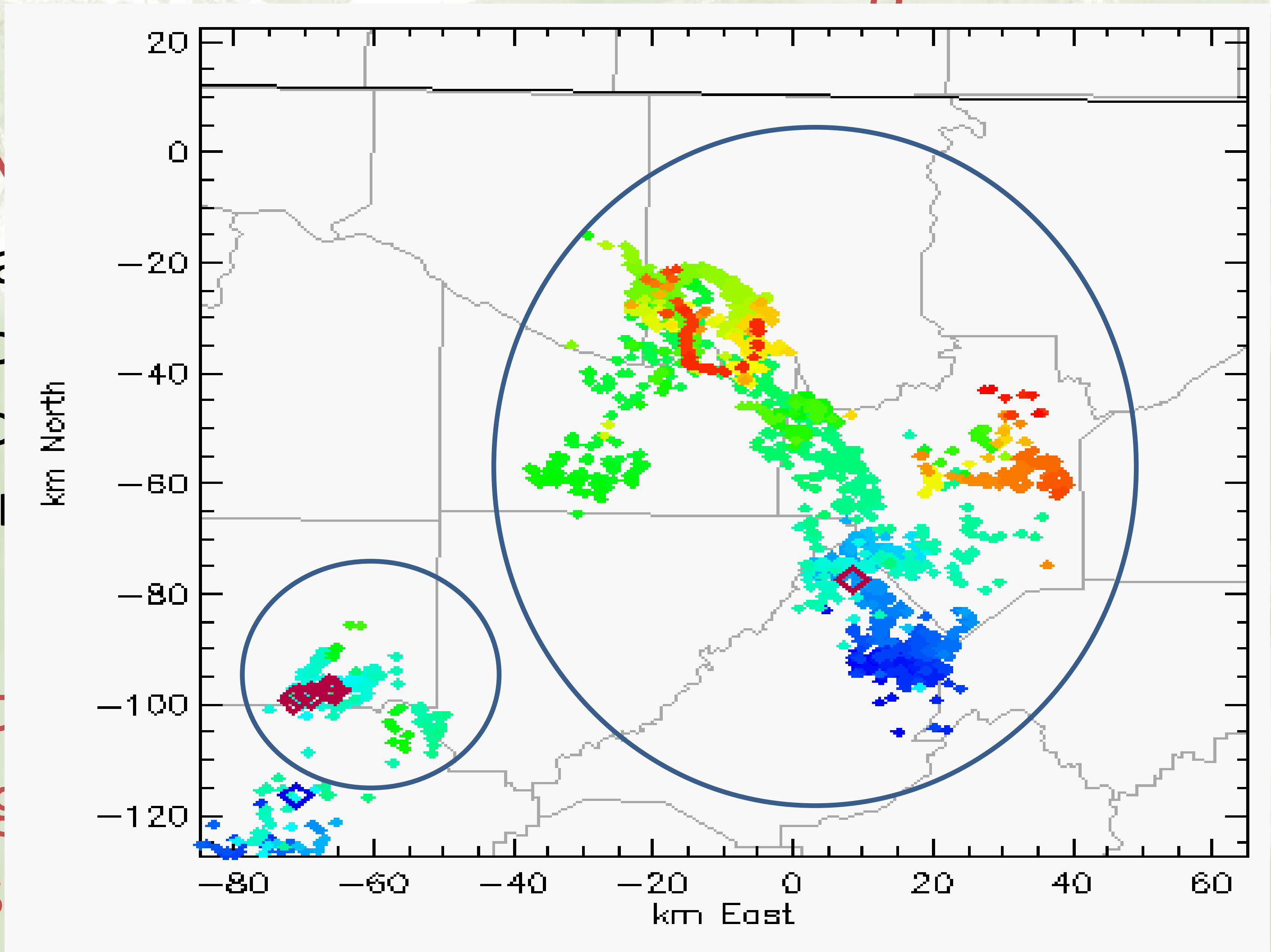


Images courtesy GOES-R Hazardous Weather Testbed blog

Motivation

Earth Science Office

- NWS wants fused decision making tools and N
  - Goa info dec wor
- What fusing datas severe weather forecasting?



Multi-Radar MultiSensor (MRMS) and ProbSevere

Earth Science Office

- MRMS – National Severe Storms Laboratory product which combines data streams from radar, satellite, lightning, models, and rain gauges to produce gridded output every 2 minutes readily available to National Weather Service offices for improved decision making.
  - Some products include:
    - Reflectivity
    - Maximum expected size of hail (MESH)
    - Azimuthal Shear (AzShear)

Image from http://www.nssl.noaa.gov/tools/decision/

- ProbSevere – NOAA/CIMSS product which uses a statistical model to predict the probability that a storm will first produce severe weather in the near term (next 60 minutes).
  - Uses radar, model output and satellite derived information to calculate probabilities (e.g., cloud top cooling, MESH, CAPE) of a storm becoming severe. (Cintineo et al. 2014)

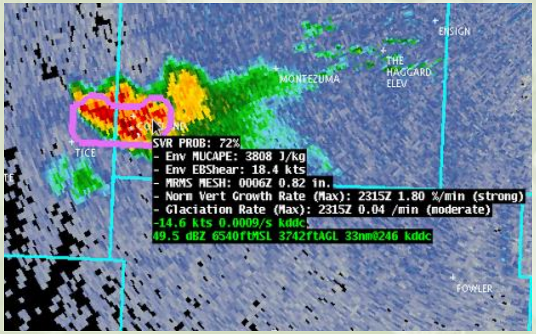


Image courtesy of the GOES-R HWT Blog

Data and Tools

Earth Science Office

- 1501 tracked thunderstorms from Schultz (2015) with storm based radar, lightning and severe weather characteristics.
  - Total lightning data from 4 lightning mapping arrays.
  - The Thunderstorm Identification Tracking, Analysis, and Nowcasting (TITAN; Dixon and Wiener 1993) was the tracking algorithm.
  - Warning Decision Support System-Integrated Information (WDSS-II) produced gridded reflectivity, MESH and AzShear.
  - Severe weather reports were taken directly from the NCEI severe report database.

Question 1: What are some of the a priori probabilities of this 1501 storm sample?

Earth Science Office

- 453 of the 1501 storms have a least one severe weather report (30%).

- 1105 of 1501 storms had MESH ≥ 25.4 mm (74%).
  - 396 storms do not have MESH ≥ 25.4 mm.

- 630 of the 1501 storms had at least 1 lightning jump (42%).
  - 871 storms do not contain at least 1 lightning jump.

Question 2 – What is the verification of these parameters using severe weather reports?

Earth Science Office

- If MESH ≥ 25.4 mm was observed what is the probability the storm was severe:
  - Probability of Detection (POD) 428/453 = 0.94
  - False Alarm Ratio (FAR) 677/1105 = 0.61

- If a lightning jump was observed, what is the probability the storm was severe:
  - POD 342/453 = 0.76
  - FAR 288/630 = 0.46

Conditional Probabilities - MESH ≥ 25.4 mm as a predictor of severe weather occurrence

Earth Science Office

$$P(C_{\text{sev}} \mid \mathbf{F}) = \frac{P(C_{\text{sev}})P(\mathbf{F} \mid C_{\text{sev}})}{P(\mathbf{F})},$$

Adapted from Cintineo et al. (2014)

- F is the observed predictor
- P(Csev) is the probability a storm is severe
- P(Cns) is the probability a storm is non-severe
- P(F) is the probability of the predictor in the storm sample
- P(F|Csev) is the probability that predictor F is found in Csev

- P(Csev|F) = $\dfrac{\frac{453}{1501}\times\frac{428}{453}}{\frac{1105}{1501}} = \dfrac{428}{1105} = 39\%$
  - P(Cns|F) = 61%
- Thus, the probability a storm is severe given the presence of MESH ≥ 25.4 mm is 39%.

Conditional Probabilities – Lightning Jump as a predictor of severe weather occurrence

Earth Science Office

$$P(C_{\text{sev}} \mid \mathbf{F}) = \frac{P(C_{\text{sev}})P(\mathbf{F} \mid C_{\text{sev}})}{P(\mathbf{F})},$$

Adapted from Cintineo et al. (2014)

- F is the observed predictor
- P(Csev) is the probability a storm is severe
- P(Cns) is the probability a storm is non-severe
- P(F) is the probability of the predictor in the storm sample
- P(F|Csev) is the probability that predictor F is found in Csev

- P(Csev|F) = $\frac{\frac{453}{1501}\times\frac{342}{453}}{\frac{630}{1501}} = \frac{342}{630} = 54\%$;
  - P(Cns|F) = 46%

- Thus, the probability a storm is severe given the presence of a lightning jump is 54%.

Question 3 – What is the verification if both indicators were present in a storm?

Earth Science Office

- 583 of 1501 thunderstorms have at least 1 lightning jump and MESH≥ 25.4 mm (39%).
- If MESH ≥ 25.4 mm and a lightning jump were observed the POD and FAR change:
  - POD 334/453 = 0.74
    - 0.20 reduction for MESH (-27%), 0.02 reduction for LJ (-3%)
  - FAR 249/583 = 0.43
    - 0.18 reduction for MESH (-41%), 0.03 reduction for LJ (-7%)

Conditional Probabilities – Using both MESH ≥ 25.4 mm Lightning Jump as a predictor of severe weather occurrence

Earth Science Office

$$P(C_{\text{sev}} \mid \mathbf{F}) = \frac{P(C_{\text{sev}})P(\mathbf{F} \mid C_{\text{sev}})}{P(\mathbf{F})},$$

Adapted from Cintineo et al. (2014)

- F is the observed predictor
- P(Csev) is the probability a storm is severe
- P(Cns) is the probability a storm is non-severe
- P(F) is the probability of the predictor in the storm sample
- P(F|Csev) is the probability that predictor F is found in Csev

- P(Csev|F) = $\dfrac{\frac{453}{1501}\times\frac{334}{453}}{\frac{630}{1501}} = \dfrac{334}{583} = 57\%$
  - P(Cns|F) = 43%
- Thus, the probability a storm is severe given the presence of MESH ≥ 25.4 mm and a lightning jump is 57%.

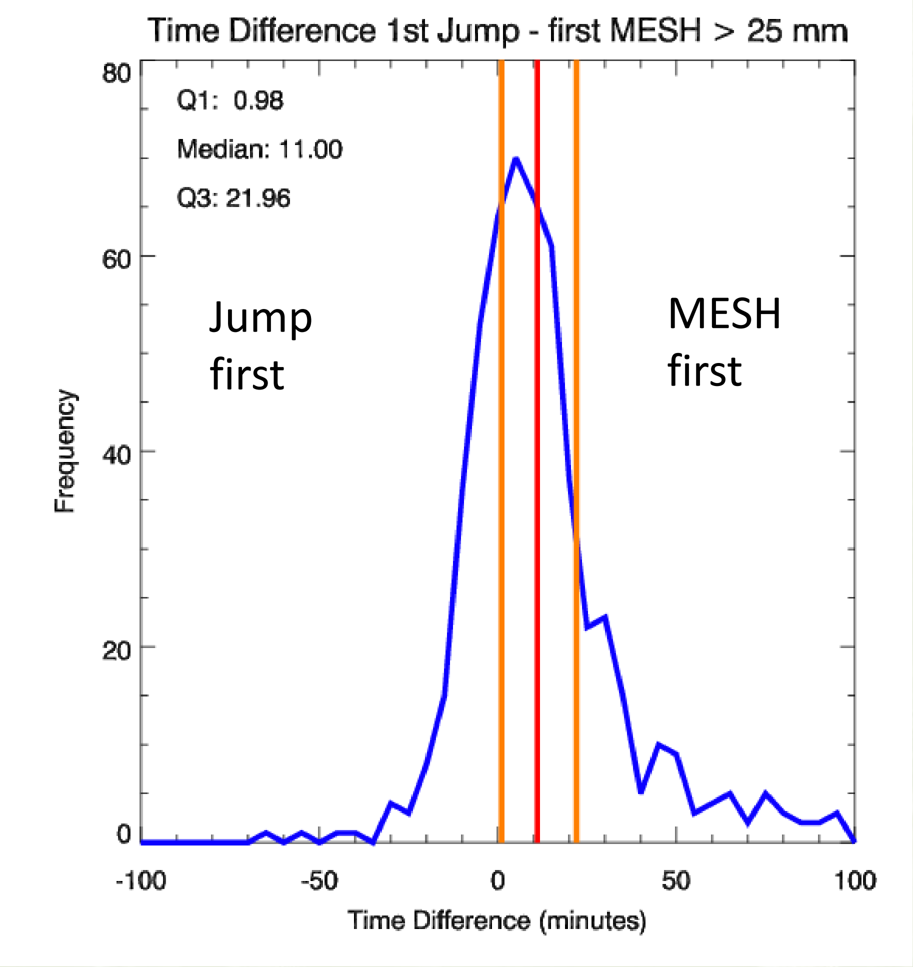
Question 4: What is the timing of the first MESH ≥ 25.4 mm and the first lightning jump?

Earth Science Office

- 537 of the 583 storms with MESH and 1 jump were tracked prior to the flash rate reaching 15 fpm.

- 25th percentile - 1 minute
- Median - 11 minutes
- 75th percentile - 22 minutes

- Take home: The majority of the time the first MESH value ≥ 25.4 mm is observed before a lightning jump occurrence.



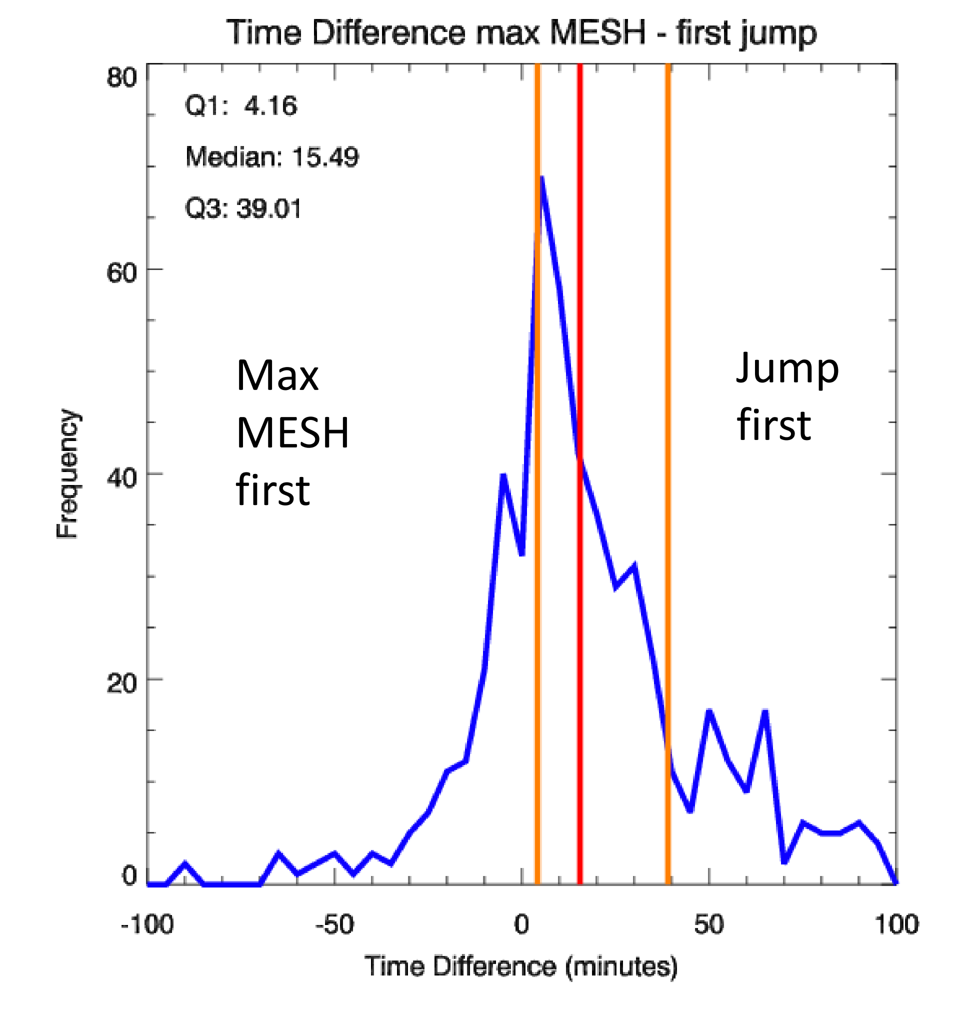
Question 5: What is the difference in timing of the maximum MESH and the first lightning jump?

Earth Science Office

- When does the maximum in MESH (i.e., intensity) occur relative to the 1st jump?

- 25th percentile - 4 minutes
- Median - 16 minutes
- 75th percentile - 39 minutes

- The majority of the time, the maximum MESH (i.e., intensity in this case) occurs after lightning jump occurrence.



Maximum MESH: Storms with lightning jumps vs non-jump storms.

Earth Science Office

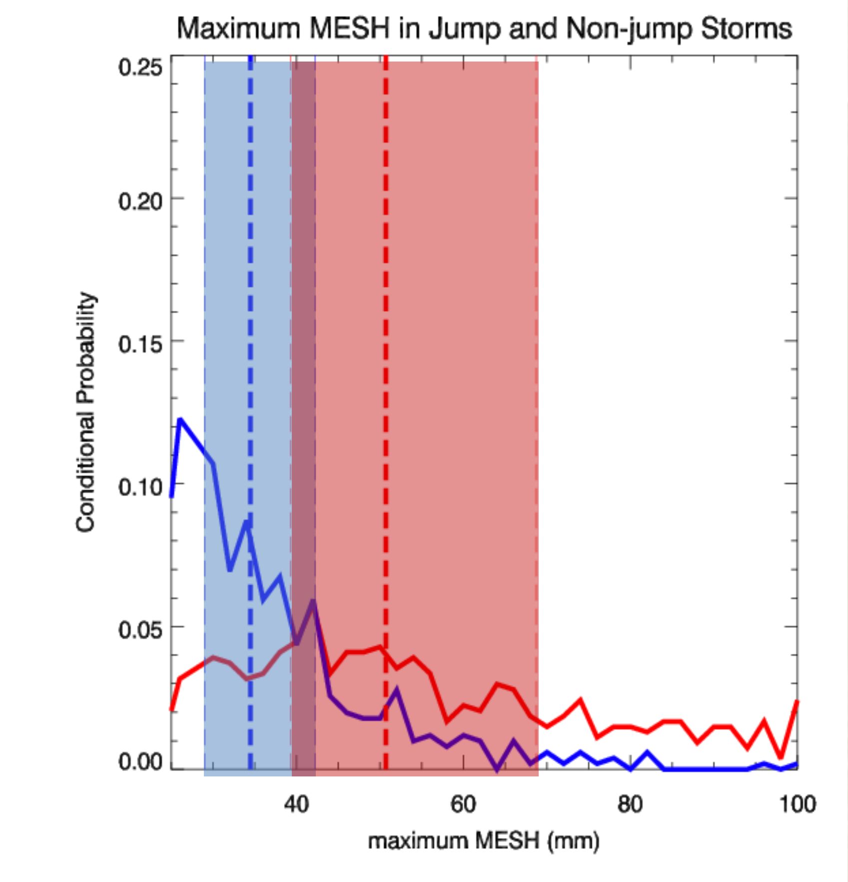
- Similar to Chronis et al. (2015), the storms with lightning jumps have larger maximum mesh magnitudes

Quartile and median values of maximum MESH with storms containing at least 1 lightning jump and MESH≥ 25.4 mm

Q1: 39.3 mm   Median: 50.5 mm   Q3: 68.7 mm

Quartile and median values of maximum MESH with storms which did not contain 1 lightning jump and MESH≥ 25.4 mm

Q1: 29.0 mm   Median: 34.5 mm   Q3: 42.2 mm



Solid red line: Distribution of the conditional probability of maximum mesh with lightning jumps Red dashed line - Median Maximum MESH
Solid blue line: Distribution of the conditional probability of maximum mesh with non-jump storms Blue dashed - Median Maximum MESH
Red shaded area: inner quartile range of maximum mesh associated with storms with jumps.
Blue shaded area: inner quartile range of maximum mesh associated with storms with jumps.

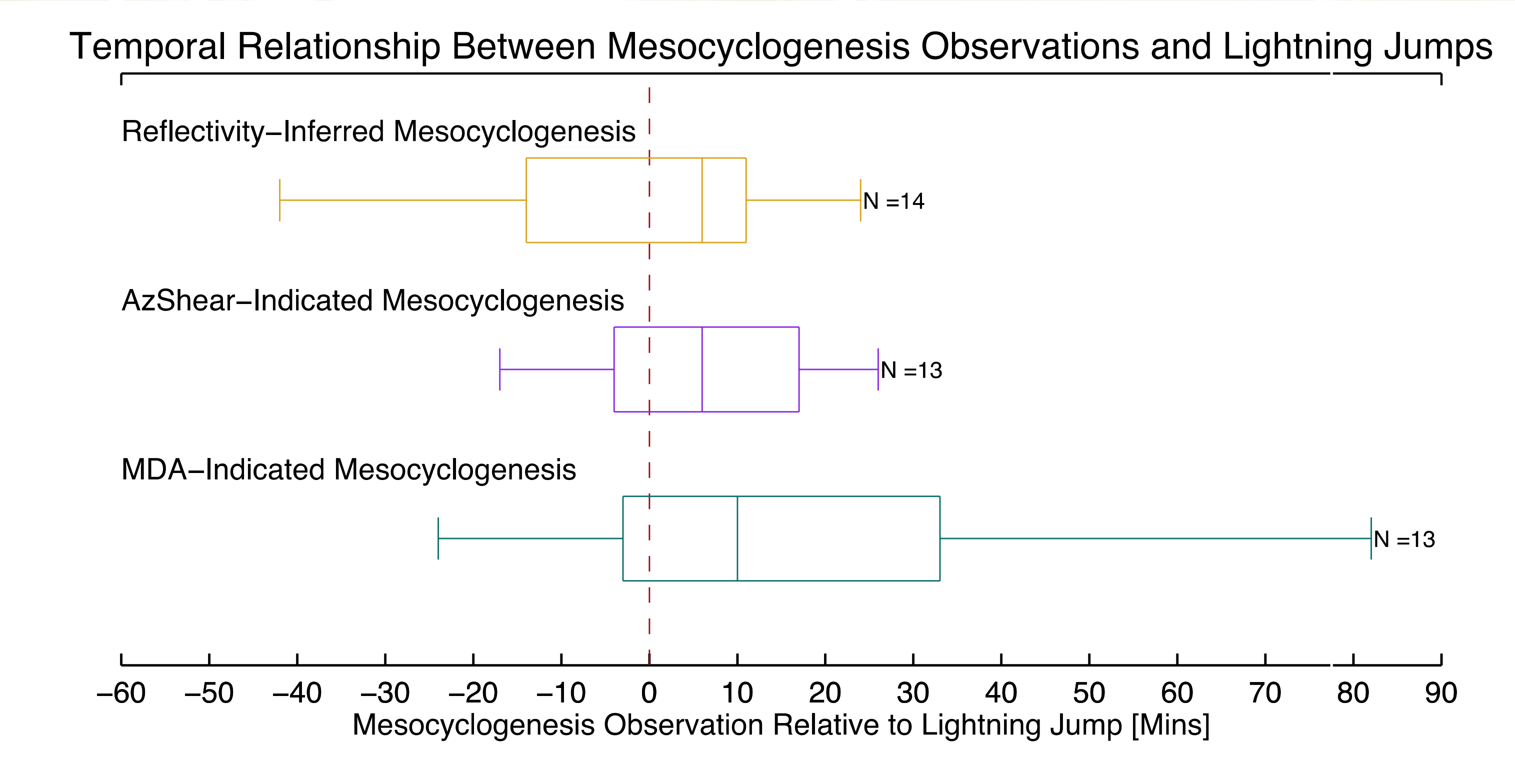
Summary

Earth Science Office

- The inclusion of the lightning jump has the potential to reduce FAR in a fused algorithm which uses radar based intensity metrics like ProbSevere.
- Relative to future fusion of algorithms and forecasting using multiple parameters the general conceptual model for timing of events should be:
  1. First MESH ≥ 25.4 mm
  2. Lightning jump
  3. Maximum MESH/Severe weather

Previous Work

Earth Science Office



Stough and Carey (2016), in review

- Chronis et al. 2015, WAF: Thunderstorms with lightning jumps had larger mean MESH values and lasted longer than storms without lightning jumps
- Over half of the time, mesocyclogenesis occurs 6-10 minutes after the 1st lightning jump occurrence.